



Research Department Report

THE INTERACTION OF ACOUSTIC TREATMENT IN AN EXPERIMENTAL SOUND CONTROL ROOM

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Summary

In small studios or control rooms the predicted reverberation time is often significantly different from that measured. The prediction is normally made from the absorption coefficients of the acoustic treatment and other materials as measured in a reverberation room.

An experimental sound control cubicle was constructed in the Acoustic Test Room at Research Department. The reverberation time was measured with many different combinations of acoustic treatment and the effective absorption coefficients of the items of acoustic treatment in different circumstances were determined.

The results were compared with reverberation time prediction calculations. From these some conclusions were drawn regarding the situations in which reverberation room measurements of absorption coefficient should be modified to give a more accurate prediction of reverberation time.

Index terms: *Acoustics; reverberation; rooms*

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1. INTRODUCTION

Reverberation time is an important measure of the acoustic quality of a room and is one which can be *specified*.

The reverberation time in a room is dependent on the absorption coefficients of the room surfaces and furnishings. Absorption coefficients are usually measured in a reverberation room. These results are used to select the quantities and types of acoustic treatment required for a particular room to achieve the design reverberation time, usually in 1/3 octave bands from 50 Hz to 10 kHz. The measured reverberation time often differs from that predicted in this way so, to a large extent, the acoustic designer must rely on experience.

The variation of absorption coefficient with ambient conditions was the subject of an earlier Research Department Report¹. This was concerned with large music studios and concert halls. To investigate similar problems in small studios, an experimental sound control room was constructed. The reverberation time was measured with the room in different conditions and the results were compared with 'room design' predictions. In many cases there were significant differences. This Report presents these results and draws some general conclusions regarding the differences between absorption coefficients measured in a reverberation room and effective absorption coefficients in an acoustically treated room.

2. THE EXPERIMENTAL SOUND CONTROL ROOM

The experimental sound control room was constructed in Research Department's Acoustic Test Room. The original bare room consisted of plastered brick walls, a concrete screed floor and a concrete ceiling slab. Below the ceiling there was ventilation ducting, designed to protrude through a false ceiling. The dimensions of the bare room were $6.7 \times 4.9 \times 3.3$ m.

The acoustic treatment for the experimental room was selected in line with current practice for sound control rooms².

The ceiling was of suspended 'acoustic' tiles.

This type of ceiling is commonly specified although fabric-covered modular absorbers are sometimes used. The tile used was not foil-backed. Foil-backed tiles have been said to be unsuitable, although the evidence for this is not known to the author.

The floor of the bare room was below the level of the door threshold, with technical trunking installed around its perimeter. Consequently, a raised floor was desirable, so an existing sectioned wood floor was re-used. Although not a typical floor construction, it was considered to be representative of a 'computer floor', sometimes used in technical areas where cables are often ducted beneath the boarding, or of a suspended wooden floor found in conversions to existing buildings.

It is normal to use carpet *tiles* in control rooms; they allow for interchangeability at wear points (e.g. the operator's position at a mixing desk) and access to underfloor ducts. A heavy contract velvet pile carpet tile was used in the experimental room.

Most of the wall area was covered in standard BBC modular absorbers². A total of 31 A2s and 81 A3s were installed in four rows. These covered the wall area except for those areas occupied by the door, technical trunking and jackfields, etc. An area of 1.2×2.4 m was also left bare to simulate an observation window.

Modular absorbers are normally covered in stretched fabric; this is for aesthetic rather than acoustic reasons, although the fabric does increase sound absorption at high frequencies. For reasons of flexibility, the fabric covering was omitted in the experimental room.

A mixing desk of plan 0.9×2.3 m was installed in the room and LS5/8 loudspeakers on stands were provided for monitoring.

Fig. 1 shows the reverberation times at various stages of the acoustic treatment of the experimental room.

3. PRACTICAL ACOUSTIC DESIGN

Acoustic design is generally done on the basis of what is convenient and has worked elsewhere.

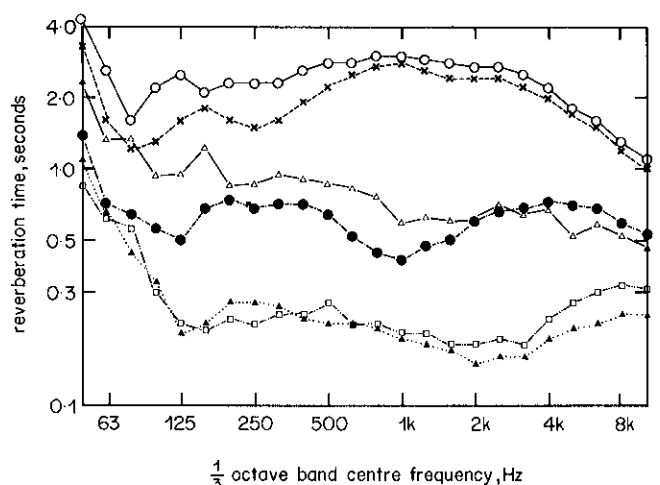


Fig. 1 - Reverberation times measured in the experimental room.

- The bare room
- ×—× - with wood floor
- △—△ - with wood floor and carpet tiles
- - with floor, carpet and ceiling tiles
- - with floor, carpet, ceiling and modular absorbers
- ▲—▲ The complete room, with all treatment, desk, loudspeakers, and diffusers

Ceiling and floor coverings are often selected for non-acoustic reasons; calculations to predict reverberation time are not necessarily employed.

The wall treatment is usually the most significant element of absorption in a room. The walls in sound control rooms are usually covered, wherever possible, with acoustic treatment, mostly in the form of BBC standard modular absorbers. The most common types of modular absorber are the A2 and A3 types. These are respectively a low frequency absorber and a mid and high frequency absorber.

The numbers of A2 and A3 absorbers used are determined by the requirement to provide bass absorption without excessive mid-band absorption. Fig. 2 illustrates a reverberation room measurement of the absorption coefficients of A2 and A3 absorbers. The peak in absorption of the A2s occurs between 100 and 125 Hz. The bass rise in a typical room is only just beginning at these frequencies. Therefore the use of too many A2s will give a dip in reverberation time at 100 and 125 Hz which only highlights the rise at lower frequencies. A reasonable compromise seems to be a ratio of A2:A3 of 3:8.

There are some rules that are normally followed when positioning modular absorbers. A2s are not normally placed at ear height and certainly not facing each other across the room; this is because they are reflective at mid and high frequencies and would cause flutter echoes. It is also normal to put A2s behind loudspeakers, to curtail the rise in bass response which results from the corner effect.

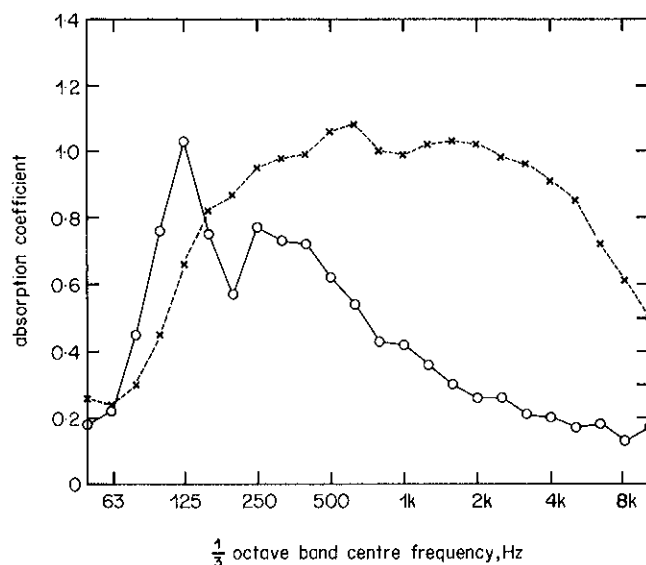


Fig. 2 - Absorption coefficients of modular acoustic absorbers, as measured in the ISO standard reverberation room.

- A2 modular absorbers
- ×—× A3 modular absorbers

4. PREDICTING A REVERBERATION TIME CHARACTERISTIC — 'ROOM DESIGN'

The conventional method for room design (to achieve a design reverberation time) is to use a formula first derived by Eyring for heavily treated rooms³. In this formula, the mean absorption coefficient which results from the respective areas and absorption coefficients of the different surfaces is used to calculate the reverberation time in the room.

The absorption coefficient values used in this calculation are normally those measured in a reverberation room. Untreated surfaces in the room can be assigned an absorption coefficient on the basis of a reverberation time measurement in the bare room. If this measurement is not possible, then standard figures can be used. The untreated area will usually be small in studios and control rooms.

Calculations are normally made for 1/3 octave bands in the range 50 Hz to 10 kHz. The quantities of the different types of acoustic treatment are adjusted until the result of the calculation is acceptably close to the design requirement.

In some cases a surface may consist of two layered components; the absorption coefficient is usually determined by the top (exposed) layer, but there may be cases when the absorption can be considered to be additive. For example, a lightweight partition wall can have significant absorption at low

frequencies, even if its surface has received another treatment; a similar example is that of carpeting on a wooden floor. In both cases, the full area of the underlying surface can be included in the room design calculation; but the absorption coefficient used for the underlying surface may need to be reduced at higher frequencies.

The use of a software spreadsheet offers a convenient way to do the calculation. An example of spreadsheet calculations for the experimental room, is given in Appendix 1.

5. SIGNIFICANCE OF ERRORS IN 'ROOM DESIGN'

To put the results of this Report into perspective it is important to be aware of the relationship between changes in absorption coefficients and changes in reverberation time.

For small changes (e.g. 10%) the percentage change in reverberation time will be approximately the same as the percentage change in mean absorption coefficient. If only one item of a room's acoustic treatment is concerned, then changing its absorption coefficient, in isolation, will have a smaller effect on the mean absorption coefficient and hence on the predicted reverberation time.

As an illustration, Fig. 3 shows the effect on the reverberation time predicted for the experimental room of $\pm 20\%$ changes in the absorption coefficients of the acoustic tile ceiling.

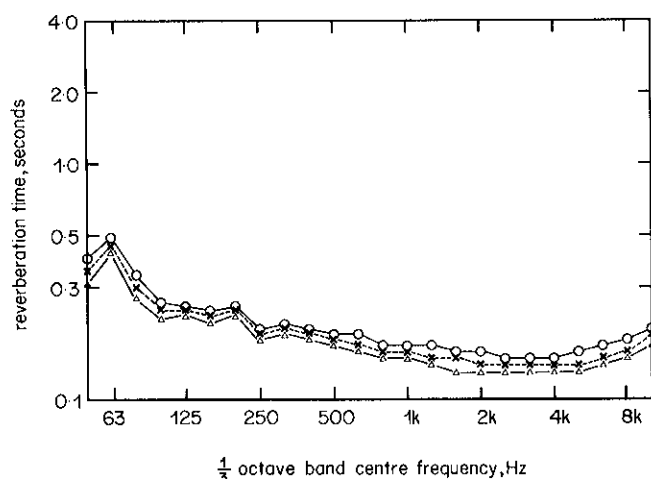


Fig. 3 - Reverberation time predictions for the experimental room showing the effect of changes in the absorption coefficients of the ceiling.

- 0.8 × ceiling absorption coefficients
- ×—× 1.0 × ceiling absorption coefficients
- △—△ 1.2 × ceiling absorption coefficients

6. ROOM DESIGN CALCULATIONS FOR THE EXPERIMENTAL ROOM

6.1 The fully treated room

Fig. 4 shows the result of a prediction as described in Section 4. This uses reverberation room measurements of the carpet, ceiling tiles and modular absorbers. The absorption coefficient of the wooden floor, although covered, is also taken into account. This was determined from measurements in the bare experimental room with and without the floor.

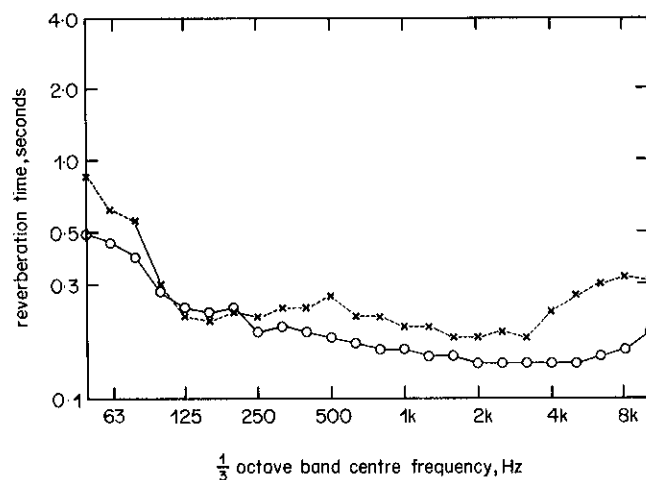


Fig. 4 - Reverberation times for the completed experimental room.

- Predicted from reverberation room measurements
- ×—× Measured

Also shown in Fig. 4 is the measured reverberation time for the fully treated room. The predicted reverberation time is significantly shorter than that measured.

6.2 Room design for individual components

The previous section shows that predicting the reverberation time for a complete room, based on reverberation room measurements of individual components, is not always very successful. It might be hoped that the effect of adding treatment to a semi-treated room could be more reliably predicted. This type of prediction is quite often required, for example, if the acoustic environment of a listening room needs to be improved.

The reverberation time of the semi-treated room, together with the known absorption coefficient of the remaining bare surfaces, can be used to calculate a mean absorption coefficient for the treated surfaces. This can be used in the room design calculation, together with the absorption coefficient of the additional treatment, in order to predict the resulting reverberation time.

Several calculations were carried out, for different components of the acoustic treatment, using this method.

6.2.1 Wall treatment

The reverberation times predicted for the addition of wall treatment to the room with ceiling and carpeted floor are compared with the practical result in Fig. 5. These curves are in better agreement than those in the previous figure.

6.2.2 Ceiling

A similar room design calculation was made to predict the effect of adding the suspended ceiling to the bare room. Fig. 6 compares this prediction with

the measured result. The agreement is poor, even though the ceiling in the otherwise bare room might be expected to behave similarly to the ceiling in a reverberation room.

6.2.3 Carpet

At one stage of the development it was found that adding carpet actually increased the reverberation time at high frequencies, as shown in Fig. 7. This could never have been predicted on the basis of reverberation room measurements.

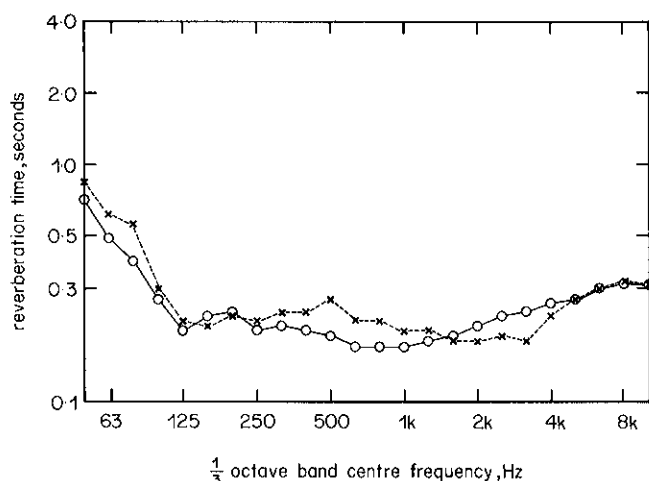


Fig. 5 - Reverberation times in the experimental room after addition of wall treatment to the otherwise treated room.

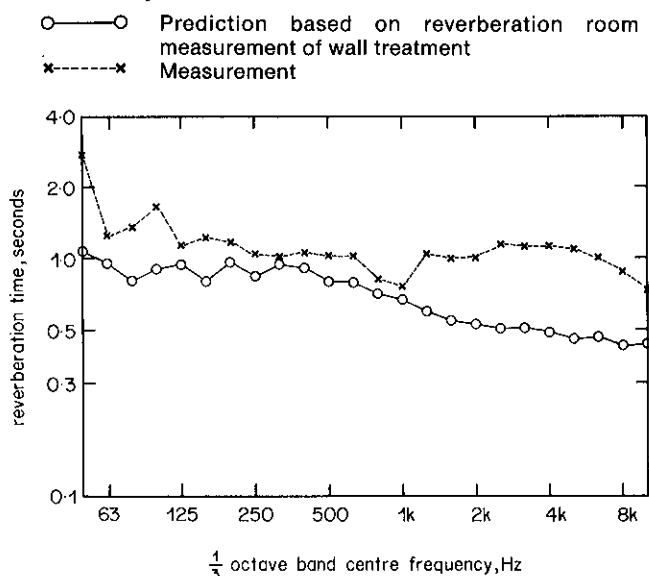


Fig. 6 - Reverberation times in the experimental room after addition of suspended acoustic tile ceiling to the bare room.

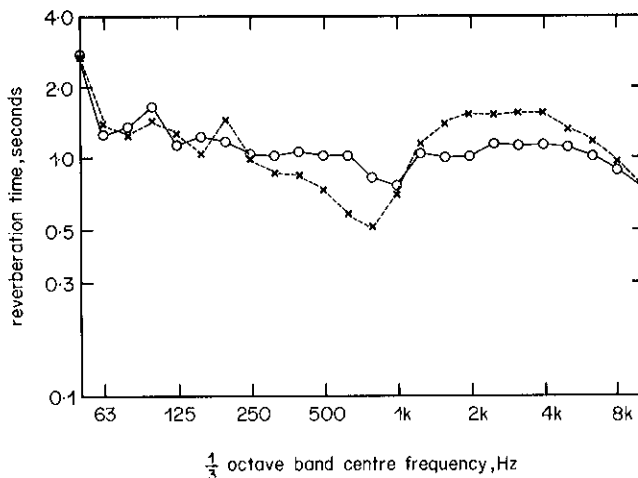


Fig. 7 - Measured reverberation times showing the effect of adding carpet tiles.

○—○ Room with ceiling tiles only
— Room with ceiling tiles plus carpet tiles on concrete floor

6.3 Discussion

The conventional room design approach has been found to be inadequate, even when simply predicting the effect of additional treatment; this raises some questions:

1. Is it ever possible to consider items of acoustic treatment independently?
2. If so, is there a more appropriate way to measure the absorption coefficients which will be used in the calculation?
3. If not, can the interdependence be taken into account in a practicable way?

7. ABSORPTION COEFFICIENT MEASUREMENTS

7.1 Reverberation room method

This is the usual method for measuring absorption coefficient and is the subject of an ISO Standard⁴. Reverberation time is measured with and

without a sample present in a reverberation room. The mean absorption coefficient, \bar{a} , of the surfaces in the reverberation room can be calculated from Eyring's formula:

$$T = 0.161 \times \frac{V}{4m - S \log(1 - \bar{a})}$$

where

T is reverberation time/s

V is room volume/m³

S is room surface area/m²

m is air absorption/nepers m⁻¹

\bar{a} is the mean absorption coefficient of the room surfaces

The absorption coefficient of the sample is calculated from:

$$\bar{a}_{\text{treated}} = \frac{(S_{\text{room}} - S_{\text{sample}}) \bar{a}_{\text{room}} + S_{\text{sample}} a_{\text{sample}}}{S_{\text{room}}}$$

The ISO standard for this measurement specifies, among other things, that the volume of the room should be 200 m³ or greater, that the sample should be in one rectangular area of about 10 m² and that there should be 'sufficient diffusion' in the room.

Before the availability of an ISO-standard reverberation room at Research Department, the 'old reverberation room' with a volume of about 100 m³ was used. Samples were set out in a similar manner to the way they would be used in a studio. For example, carpet would be measured as one patch on the floor but wall treatment would be spread over a number of room surfaces. Diffusers were not used. The usual sample area was about 9 m² (100 ft²).

The ISO-standard reverberation room (the Transmission Suite Receive Room) has a volume of 202 m³. Proving experiments⁵ have shown that diffusers are required and these take the form of suspended acrylic sheets. The sample is usually to the ISO-standard, i.e. 10 m² in one patch.

7.2 Reproducibility of reverberation room measurements

Different reverberation rooms and different methods give different results. These differences put into perspective the differences between measured and effective absorption coefficients of items of acoustic treatment.

Fig. 8 compares results for a sample of ceiling tiles (supported over an air space) measured in the old

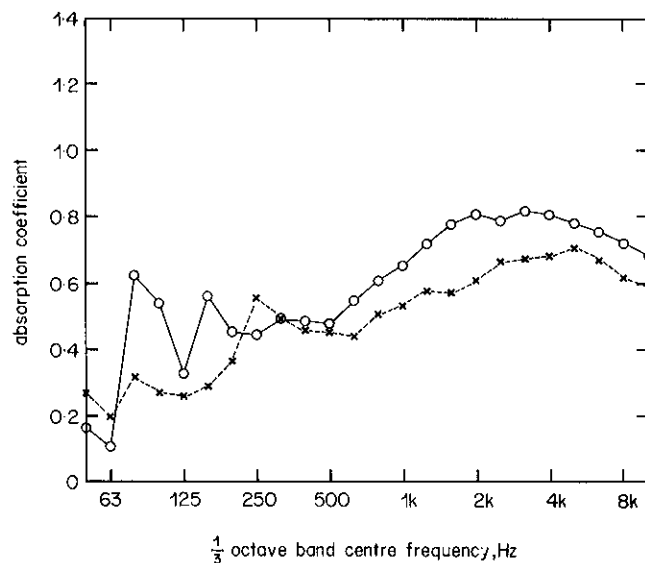


Fig. 8 - The absorption coefficients of a sample of ceiling tiles measured in different reverberation rooms.

○—○ ISO standard reverberation room
×---× Old reverberation room

reverberation room and measured in the ISO-reverberation room. Except for some irregularity at low frequency the results are generally within 20%.

Fig. 9 compares results for a sample of A3 modular absorbers in the old reverberation room measured as a single patch and then measured as four patches distributed over different room surfaces. In this case the difference is quite significant, but had diffusers been used in the room the difference would probably have been much smaller.

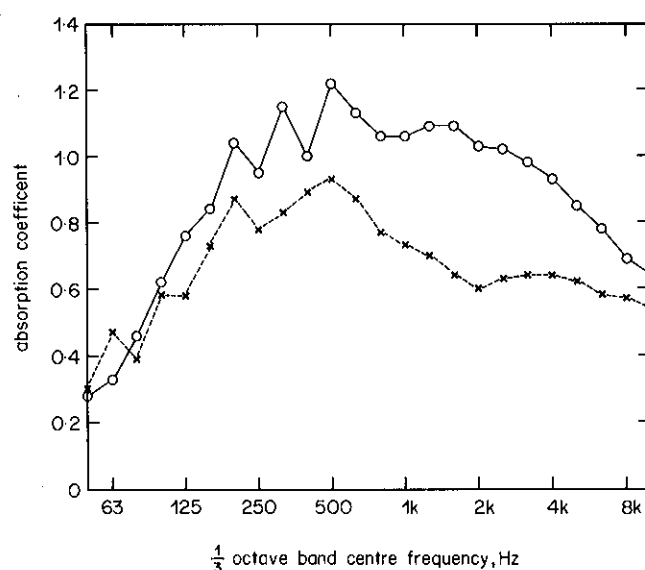


Fig. 9 - Two measurements of A3 modular absorbers in the old reverberation room.

○—○ A3 modular absorbers on battens: 4 patches of 3 x 2 on walls and floor
×---× A3 modular absorbers on battens: 6 x 4 patch on floor

The measured values also depend on sample area but, in a reverberation room with adequate diffusion, the effect is comparatively small.

For the purpose of room design the lack of precision of reverberation room measurements is not as significant as might be imagined. Note in particular that in both the above examples the corresponding curves are of a similar shape.

7.3 *In situ* measurements

More significant differences are obtained when absorption coefficient measurements are made *in situ*. Two such methods were investigated using the experimental room: (i) measure the item on its own in an otherwise bare room, and (ii) measure the effect of removing the item from a fully treated room.

For method (i) the absorption coefficient is determined as it would be using a reverberation room.

For method (ii) the required absorption coefficient is determined from measurements of reverberation times in the room fully treated, and with the item under test removed. The mean absorption coefficient of the bare surfaces is also required and this is obtained from the reverberation time of the empty room.

Let \bar{a}_{full} be the mean absorption coefficient of the fully treated room, let \bar{a}_{minus} be the mean absorption coefficient of the room with the sample removed, and let \bar{a}_{bare} be the mean absorption coefficient of the bare room.

Let S_{total} be the total surface area of the room, let $S_{removed}$ be the area of sample removed, and let S_{rest} be the area remaining.

$$\bar{a}_{minus} = \frac{S_{removed} \bar{a}_{bare} + S_{rest} \bar{a}_{rest}}{S_{total}}$$

$$\bar{a}_{full} = \frac{S_{removed} a_{sample} + S_{rest} \bar{a}_{rest}}{S_{total}}$$

$$S_{removed} a_{sample} = S_{total} \bar{a}_{full} - S_{total} \bar{a}_{minus} + S_{removed} \bar{a}_{bare}$$

$$a_{sample} = \frac{S_{total}}{S_{removed}} [\bar{a}_{full} - \bar{a}_{minus}] + \bar{a}_{bare}$$

This method is much more sensitive to errors because removing an item from a treated room may cause only a small difference in reverberation time.

7.4 Results

Three measures of absorption coefficient are compared. These are from the standard reverberation room, from the test sample alone in the otherwise bare experimental room, and from the removal of the test sample from the otherwise completely treated experimental room.

7.4.1 Wall treatment

Fig. 10 shows the absorption coefficients measured for the wall treatment. The absorption coefficients measured using the bare room show a slightly erratic variation with frequency due to unevenness in the reverberation time of the 'empty' room which in fact contained some ceiling components, the wooden floor and a mixing desk. For use in subsequent room design calculations the result was adjusted slightly to reduce the irregularities since they were not considered genuine properties of the modular absorbers. The absorption coefficient measured was approximately 75% of the reverberation room result except at the low and high frequency extremes.

The absorption coefficient measured by removing all the wall treatment from the fully treated room is similar to the bare room result except that it is significantly higher in the range 1250 to 3150 Hz and lower at extreme high frequencies.

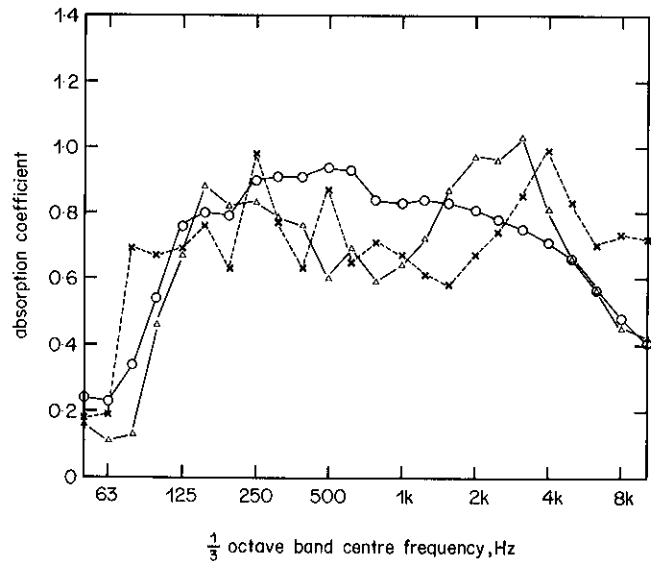


Fig. 10 - Absorption coefficient measurements on the wall treatment used in the experimental room.

- Reverberation room measurements of A2 and A3 absorbers in the ratio 31:81
- *—*—* One wall of absorbers measured in the otherwise bare room
- △—△ Absorbers measured by removal from the fully treated room

7.4.2 Ceiling

Fig. 11 shows the absorption coefficients measured for the ceiling tiles. The curves show some similarity in the mid-frequency range but at high frequency the reverberation room result shows much more absorption than either of the *in situ* results. Below 125 Hz the reverberation room result shows erratic and rather high absorption. This result was considered unreliable because it was probably a property of the suspension system rather than of the tiles. (For the test the tiles were supported over an enclosed air space 300 mm deep). Therefore, in room design calculations the 125 Hz value was used for the lower frequency bands.

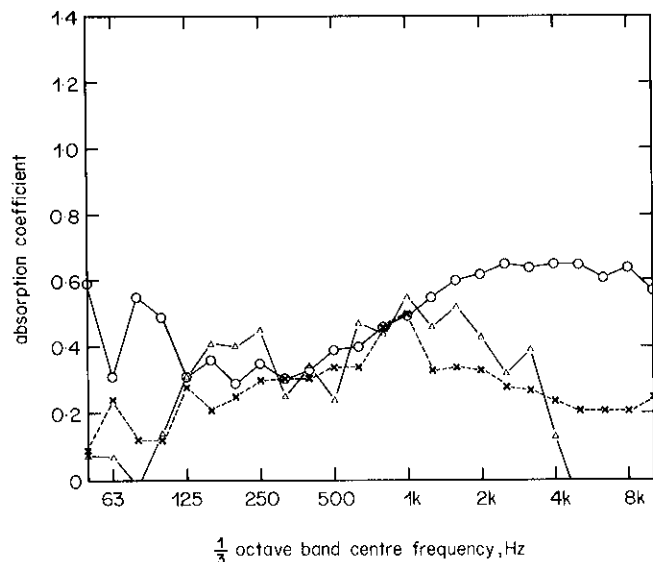


Fig. 11 - Absorption coefficient measurements on the ceiling tiles used in the experimental room.

- Reverberation room measurement
- ×—× The suspended ceiling measured in the otherwise bare room
- △—△ The ceiling tiles measured by removal from the fully treated room

7.4.3 Floor/carpet

In this case there is the additional complication that the wood floor was present for some measurements and not for others. Therefore, two comparisons are shown, firstly for the carpet on its own and secondly for the carpet and wood floor.

Fig. 12 shows the absorption coefficients measured for the carpet. The removal measurement for the carpet shows high absorption around 160 Hz and low (even negative) absorption at high frequencies. The low frequency effect may be due to interaction with the wood floor. The high frequency effect is similar to that mentioned in Section 6.2.3.

Fig. 13 shows the absorption coefficients

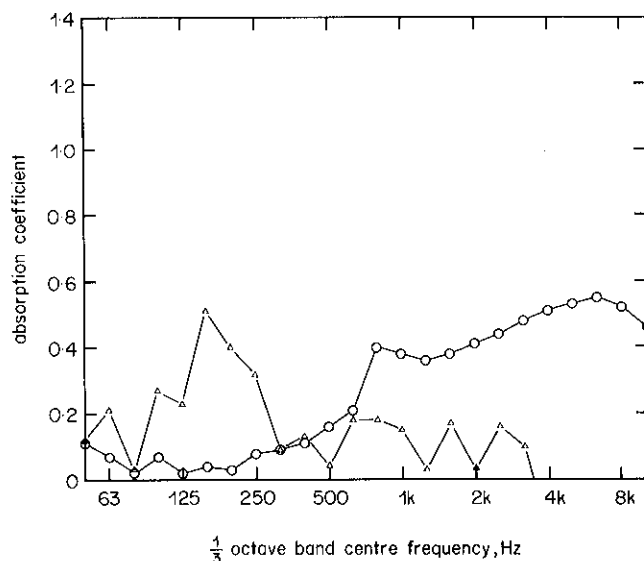


Fig. 12 - Absorption coefficient measurements on the carpet tiles used in the experimental room.

- Reverberation room measurement
- △—△ The carpet tiles measured by removal from the fully treated room

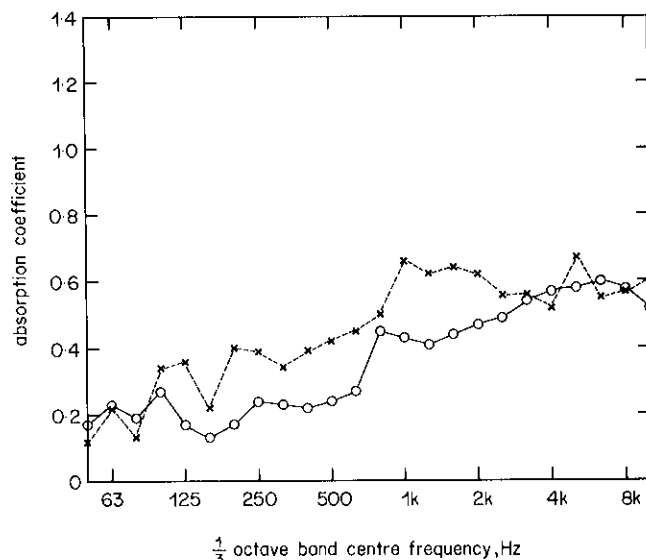


Fig. 13 - Absorption coefficient measurements on the carpet tiles and wood floor used in the experimental room.

- Carpet tiles measured in rev room plus wood floor
- ×—× The carpet tiles on wood floor measured in the otherwise bare room

measured for the carpet/floor combination. The bare room measurement is uniformly higher than the sum of the two reverberation room results. This may be because the absorption of carpet and wood floor together is greater than the sum of the individual absorptions.

7.4.4 Statistical errors

The statistical errors in absorption coefficients measured by the reverberation room method are of

the order of 0.02 units of absorption coefficient and so would be barely visible on these curves.

The statistical errors in absorption coefficients measured in the bare experimental room are of the order of 0.04 units of absorption coefficient at mid frequencies and up to twice this at low frequencies.

The statistical errors in absorption coefficients measured by removing items from the treated room are of the order of 0.15 units of absorption coefficient at mid frequencies and up to twice this at low frequencies. These uncertainties are comparatively large.

7.4.5 Discussion

In general the *in situ* absorption coefficients are lower than the reverberation room results. This is consistent with the fact that the conventional prediction for the experimental room gave too short a reverberation time. The removal results, as expected, appear slightly unreliable.

There is not a consistent relationship between the different types of measurement. This is unfortunate because the *in situ* measurements are not practical for real situations. It is necessary to be able to make estimates of the effective absorption coefficients from the reverberation room results.

8. ROOM DESIGN USING ALTERNATIVE MEASURES OF ABSORPTION COEFFICIENT

Fig. 14 shows the result of a reverberation time prediction based on absorption coefficients measured using the bare experimental room. This prediction shows good agreement with the measured result, and is better than that obtained from reverberation room measurements (Fig. 4).

Fig. 15 shows the result of a reverberation time prediction based on absorption coefficients measured by removing items from the fully treated experimental room. This prediction is typically about 50% too high. This discrepancy cannot be explained by the statistical errors because the result is consistently too high.

It is well known (see for example Ref. 1) that as the area of absorber in a room is increased, its effective absorption coefficient decreases. This is, in general terms, why the absorption coefficients measured in a reverberation room are greater, and why the absorption coefficients measured by removing items from a treated room are lower, than the effective

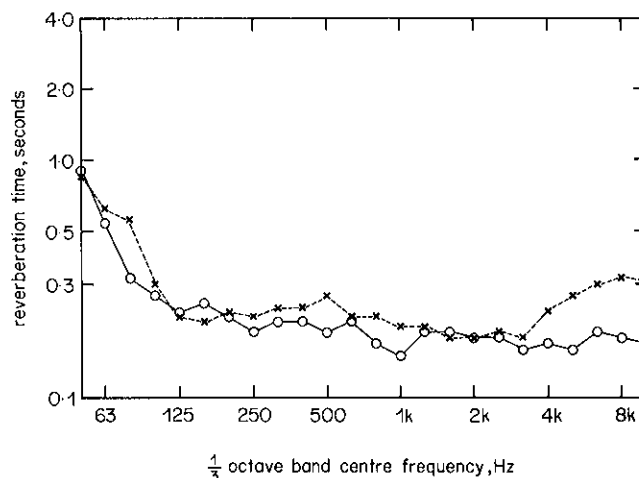


Fig. 14 - Reverberation times for the fully treated experimental room.

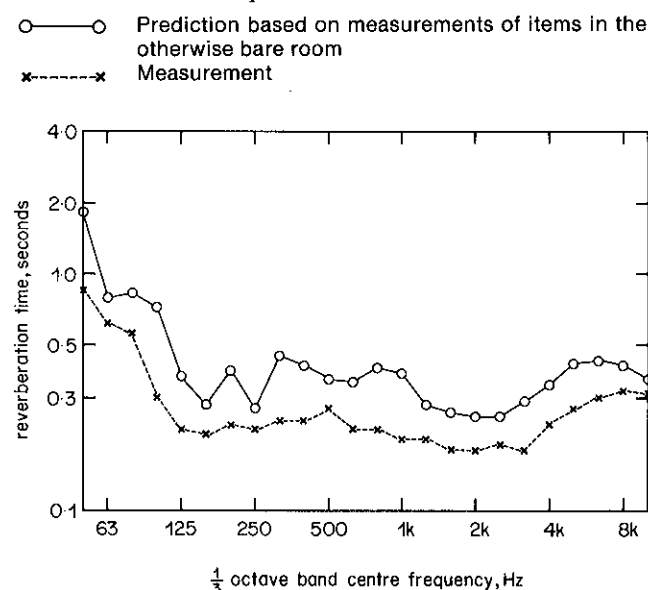


Fig. 15 - Reverberation times for the fully treated experimental room.

○—○ Prediction based on measurements of items by removal from the fully treated room
 x---x Measurement

absorption coefficients observed in real rooms. However, this effect appears to be much more marked for the 'removal' measurements. It is also clear that other factors are very significantly modifying the effective absorption coefficients.

9. PREDICTIONS FOR THE ROOM IN VARIOUS PARTIALLY TREATED CONDITIONS

It is clear that the effective absorption coefficient of an item is dependent on the other items in the room. One important factor seems to be the balance of absorption between the mutually perpendicular room surfaces. If this is uneven, then some effective absorption coefficients may be reduced. Reflections

between opposing less absorbent surfaces will tend to dominate in the reverberant decays. The following sub-sections will examine this effect for various room conditions and compare predictions of reverberation time with measurements.

The absorption coefficients measured by removing items from the experimental room were subject to large statistical errors and were found to be consistently too low to give a reasonable prediction for the fully treated room. This method is therefore not considered in the following sections.

9.1 Ceiling only

This is the case considered in Section 6.2.2 (Fig. 6). As there is only one item of treatment present, the prediction, using the measurements made in the bare experimental room, would obviously give the correct answer.

The prediction based on reverberation room measurements is less than the measured result, particularly above 1 kHz. The discrepancy at low frequencies is probably due to the difference between the suspension method and the void depth for the ceiling in the reverberation room and the ceiling in the experimental room. At higher frequencies, it is very likely that the discrepancy is due to the fact that horizontal reflections between the walls dominate the reverberation.

9.2 Ceiling plus carpet laid directly on concrete floor

Fig. 16, when compared with Fig. 6, shows that putting carpet on the concrete floor actually increased the reverberation time at high frequencies. The resulting measured reverberation time characteristic shows a dramatic rise above 800 Hz. Both predictions are very inaccurate in this region, although the prediction based on measurements using the bare experimental room does show a small rise and is also more accurate at low frequencies.

It is likely that reducing the decay time in the vertical direction has made the longer decay of reflections between the walls even more dominant.

9.3 Ceiling plus carpet laid on wood floor

Fig. 17 shows the results obtained from predictions and measurements for the ceiling, plus carpet laid on a wood floor. The prediction based on reverberation room results is in close agreement with the measurement up to and including 1 kHz. The prediction based on bare room measurements is less close in this region. At higher frequencies the

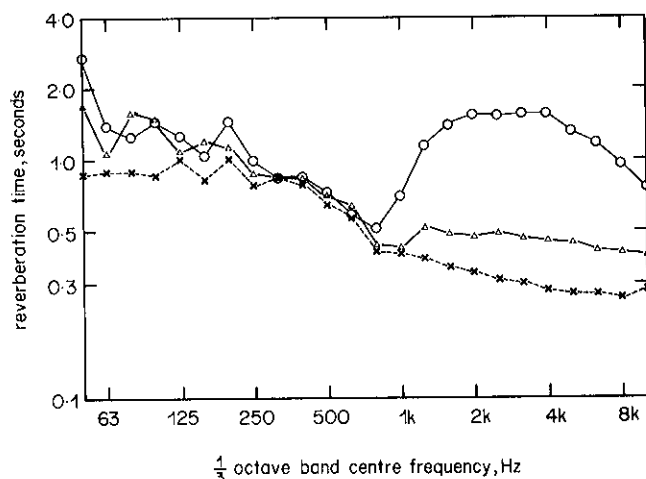


Fig. 16 - Reverberation times for the experimental room with ceiling tiles plus carpet laid directly on concrete floor.

○—○ Measurement
 ×—× Prediction based on reverberation room measurements
 △—△ Prediction based on measurements in the bare room

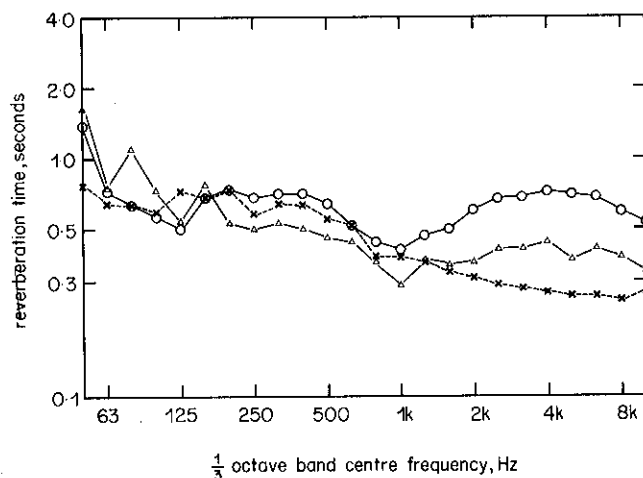


Fig. 17 - Reverberation times for the experimental room with ceiling plus carpet laid on wood floor.

○—○ Measurement
 ×—× Prediction based on reverberation room measurements
 △—△ Prediction based on measurements in the bare room

measured reverberation time rises. The prediction based on reverberation room results fails to show this rise at all. The prediction based on bare room measurements shows a small rise.

The region above 1 kHz corresponds with the range over which the excess of absorption of floor and ceiling over that of the walls is greatest. However, the magnitudes of the absorption coefficients vary slowly with frequency and do not explain the size and sudden onset of this effect. The effect is similar to, although less pronounced than, that in the previous section.

9.4 Carpet on wood floor plus wall treatment

Fig. 18 shows the results obtained from predictions and measurement for the room with carpet on wood floor plus wall treatment. In this case both predictions are very similar, with near agreement except within the range 250 to 1600 Hz where the measured reverberation time is significantly greater than the predictions.

There is an excess of absorption on the walls compared with the floor which decreases at higher frequencies but this has only a limited correspondence with the difference between predictions and measurement.

9.5 Bare wood floor plus ceiling and wall treatment

Fig. 19 shows the results obtained from predictions and measurement for the room with bare wood floor plus ceiling and wall treatment. The prediction based on bare room measurements is in approximate agreement with the measurement apart from a rise above 1 kHz which did not occur in the measurement. The prediction based on reverberation room measurements is in close accord above 1 kHz; below this frequency, the measured reverberation time is significantly higher than the prediction.

There is an excess of absorption of the walls over the floor and ceiling but this is reduced at higher frequencies; this may account for the better agreement in this frequency range of the prediction based on reverberation room measurements.

9.6 Discussion

It seems that at low frequencies it is uncertainty in the reverberation room measurements which is the principal source of error. The wood floor/carpet combination was not measured in a reverberation room. For the ceiling measurement the test conditions were only an approximation to that encountered in a real room.

At higher frequencies the effect of an imbalance of absorption on the different room surfaces appears to be significant. Where there are comparatively reflective surfaces opposite each other the reverberation time will be increased. This effect occurs above 1 kHz.

There is not much to choose between predictions based on reverberation room measurements and those based on measurements in the bare experimental room. The slightly reduced absorption of wall treatment measured using the bare experimental room seems to be relevant for the fully treated room.

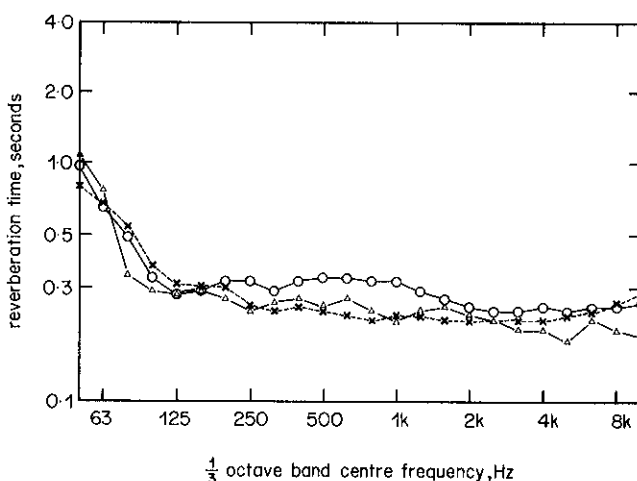


Fig. 18 - Reverberation times for the experimental room with carpet on wood floor plus wall treatment.

○ — ○ Measurement
× — × Prediction based on reverberation room measurements
△ — △ Prediction based on measurements in the bare room

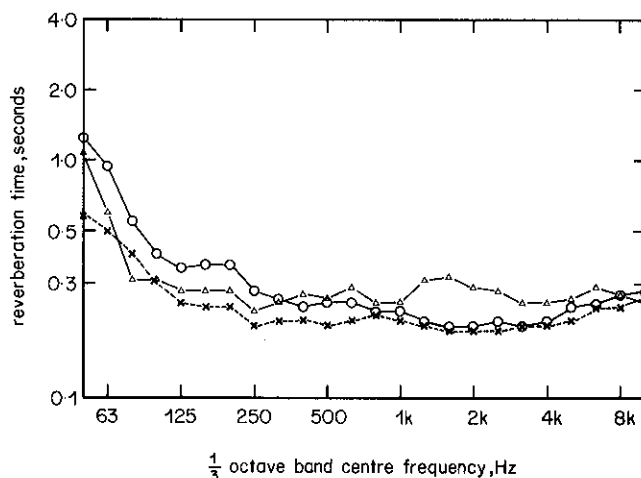


Fig. 19 - Reverberation times for the experimental room with bare wood floor plus ceiling and wall treatment.

○ — ○ Measurement
× — × Prediction based on reverberation room measurements
△ — △ Prediction based on measurements in the bare room

At high frequencies, the absorption coefficients of the ceiling and carpet measured in the bare experimental room are lower than those measured in the reverberation room. These reduced absorption coefficients do seem to be representative of what happens in the treated room. However, the magnitude of this effect varies greatly.

10. THE EFFECT OF DIFFUSION ON REVERBERATION TIME

Diffusion is the term used to describe the randomness of the sound field in a room. The field is

perfectly diffuse if it has uniform distribution of sound energy throughout its volume and if the directions of propagation at arbitrarily chosen points are wholly random. Diffusion in a room can be increased by adding elements which reflect sound at oblique angles.

Fig. 20 shows the results of measurements in the room with about half the wall treatment removed. Diffusion was added by suspending three acrylic sheets each 1.8 m by 1.2 m in the room. The presence of diffusing elements in the experimental room reduced the reverberation time in the upper half of the frequency range.

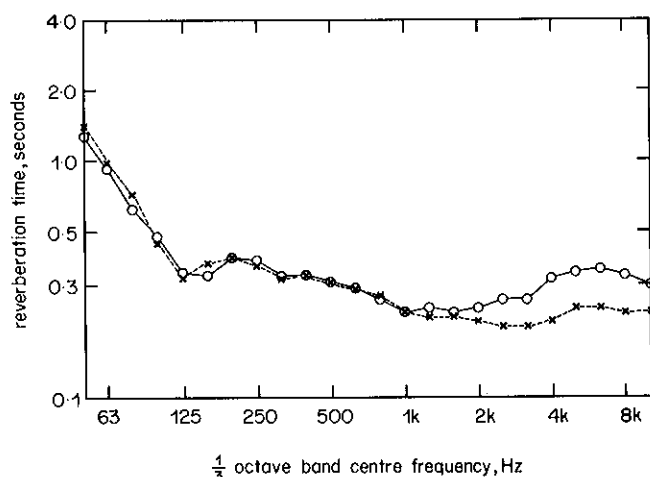


Fig. 20 - Reverberation times for the experimental room showing the effect of suspended diffusing sheets.

- — Complete room minus 26 A3s and 23 A2s
- × - - - Complete room minus 26 A3s and 23 A2s with 3 suspended diffusers

Most materials have a lower absorption at glancing incidence. Increasing the diffusion causes less sound to travel parallel to the room surfaces (such as it does if it reflects between an opposing pair of walls). This gives more efficient absorption by the majority of the acoustic treatment and results in a reduction in reverberation time. Reflections are more significant at shorter wavelengths where diffraction effects are less significant. This is why the effect of diffusion is greater at high frequencies.

The dramatic rises in reverberation time at high frequencies in some of the examples of the previous section would have been reduced by the presence of diffusing elements in the room.

11. CONCLUSIONS

The series of experiments in the experimental sound control room has not shown a clear cut method for the accurate prediction of reverberation time in small rooms. Statistical errors in the determination of

absorption coefficients do not account for the differences observed between predictions and measurements.

Reverberation room measurements of absorption coefficients have been found to be a reasonable guide to the effective absorption of items in a room which has an even distribution of absorption over different room surfaces. However, it has been found that predictions (based on reverberation room measurements) for rooms in which there is an uneven distribution of absorption and a lack of diffusing elements are unreliable. Typical sound control rooms do suffer from this imbalance in the distribution of absorption because the walls are usually heavily treated in comparison with the floor and ceiling.

Determining the absorption coefficient of an item by removing it from a treated room gave too low a value for use in room design calculations and was subject to large statistical errors.

Determining the absorption coefficient of an item by covering one surface of an otherwise bare room sometimes gave an indication of how the effective absorption coefficient in the treated room could differ from that measured in a reverberation room.

In particular, an acoustic tile ceiling gave less absorption at high frequency than was measured in a reverberation room, and short pile carpet tiles gave unpredictable results with apparently negative absorption coefficients at high frequencies in some cases.

12. REFERENCES

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APPENDIX 1

Room Design Spreadsheet

length: 6.70
width: 4.90
height: 2.70

volume: 88.64
surface: 128.30

| | | | | | | | | | |
|-----------|--|-------|-------|-------|-------|-------|-------|---------|--|
| quantity: | | | | | | | | | |
| area: | | 22.32 | 32.83 | 32.83 | 32.83 | 31.00 | 81.00 | average | |
| | | | | | | 11.16 | 29.16 | 0.16 | |

| band | air abs | rt empty | bare wall | ceiling | floor | carpet | A2 box | A3 box | rev time |
|------|---------|----------|-----------|---------|-------|--------|--------|--------|----------|
| 17 | 0 | 4.30 | 0.03 | 0.59 | 0.06 | 0.11 | 0.18 | 0.26 | 0.35 |
| 18 | 0 | 2.60 | 0.04 | 0.31 | 0.16 | 0.07 | 0.22 | 0.24 | 0.45 |
| 19 | 0 | 1.60 | 0.07 | 0.55 | 0.17 | 0.02 | 0.45 | 0.30 | 0.30 |
| 20 | 0 | 2.20 | 0.05 | 0.49 | 0.20 | 0.07 | 0.76 | 0.45 | 0.24 |
| 21 | 0 | 2.50 | 0.04 | 0.31 | 0.15 | 0.02 | 1.03 | 0.66 | 0.24 |
| 22 | 0 | 2.10 | 0.05 | 0.36 | 0.09 | 0.04 | 0.75 | 0.82 | 0.23 |
| 23 | 0 | 2.30 | 0.05 | 0.29 | 0.14 | 0.03 | 0.57 | 0.87 | 0.24 |
| 24 | 0 | 2.30 | 0.05 | 0.35 | 0.16 | 0.08 | 0.77 | 0.95 | 0.19 |
| 25 | 0 | 2.30 | 0.05 | 0.30 | 0.14 | 0.09 | 0.73 | 0.98 | 0.20 |
| 26 | 0 | 2.60 | 0.04 | 0.33 | 0.11 | 0.11 | 0.72 | 0.99 | 0.19 |
| 27 | 28 | 2.80 | 0.04 | 0.39 | 0.09 | 0.16 | 0.62 | 1.06 | 0.18 |
| 28 | 37 | 2.80 | 0.04 | 0.40 | 0.06 | 0.21 | 0.54 | 1.08 | 0.17 |
| 29 | 48 | 3.00 | 0.03 | 0.46 | 0.05 | 0.40 | 0.43 | 1.00 | 0.16 |
| 30 | 59 | 3.00 | 0.03 | 0.49 | 0.05 | 0.38 | 0.42 | 0.99 | 0.16 |
| 31 | 71 | 2.90 | 0.03 | 0.55 | 0.05 | 0.36 | 0.36 | 1.02 | 0.15 |
| 32 | 85 | 2.80 | 0.03 | 0.60 | 0.06 | 0.38 | 0.30 | 1.03 | 0.15 |
| 33 | 107 | 2.70 | 0.03 | 0.62 | 0.06 | 0.41 | 0.26 | 1.02 | 0.14 |
| 34 | 126 | 2.70 | 0.03 | 0.65 | 0.06 | 0.44 | 0.26 | 0.98 | 0.14 |
| 35 | 162 | 2.50 | 0.03 | 0.64 | 0.06 | 0.48 | 0.21 | 0.96 | 0.14 |
| 36 | 217 | 2.20 | 0.03 | 0.65 | 0.06 | 0.51 | 0.20 | 0.91 | 0.14 |
| 37 | 302 | 1.80 | 0.04 | 0.65 | 0.05 | 0.53 | 0.17 | 0.85 | 0.14 |
| 38 | 437 | 1.60 | 0.04 | 0.61 | 0.06 | 0.55 | 0.18 | 0.72 | 0.15 |
| 39 | 648 | 1.30 | 0.04 | 0.64 | 0.06 | 0.52 | 0.13 | 0.61 | 0.16 |
| 40 | 976 | 1.10 | 0.03 | 0.57 | 0.06 | 0.46 | 0.17 | 0.50 | 0.19 |